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Nagarajan et al.

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(54) **MULTICAST LOAD BALANCING IN MULTIHOMING EVPN NETWORKS**

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(56) **References Cited**

U.S. PATENT DOCUMENTS

8,125,928 B2 *	2/2012	Mehta	....	H04L 12/4625 370/254
8,953,446 B1	2/2015	Wang et al.		

(Continued)

FOREIGN PATENT DOCUMENTS

EP	3013006 A1	4/2016
EP	3070877 A1	9/2016

OTHER PUBLICATIONS

Sajassi, et al., "BGP MPLS-Based Ethernet VPN," Internet Engineering Task Force; RFC 7432, Feb. 2015, 56 pp.

(Continued)

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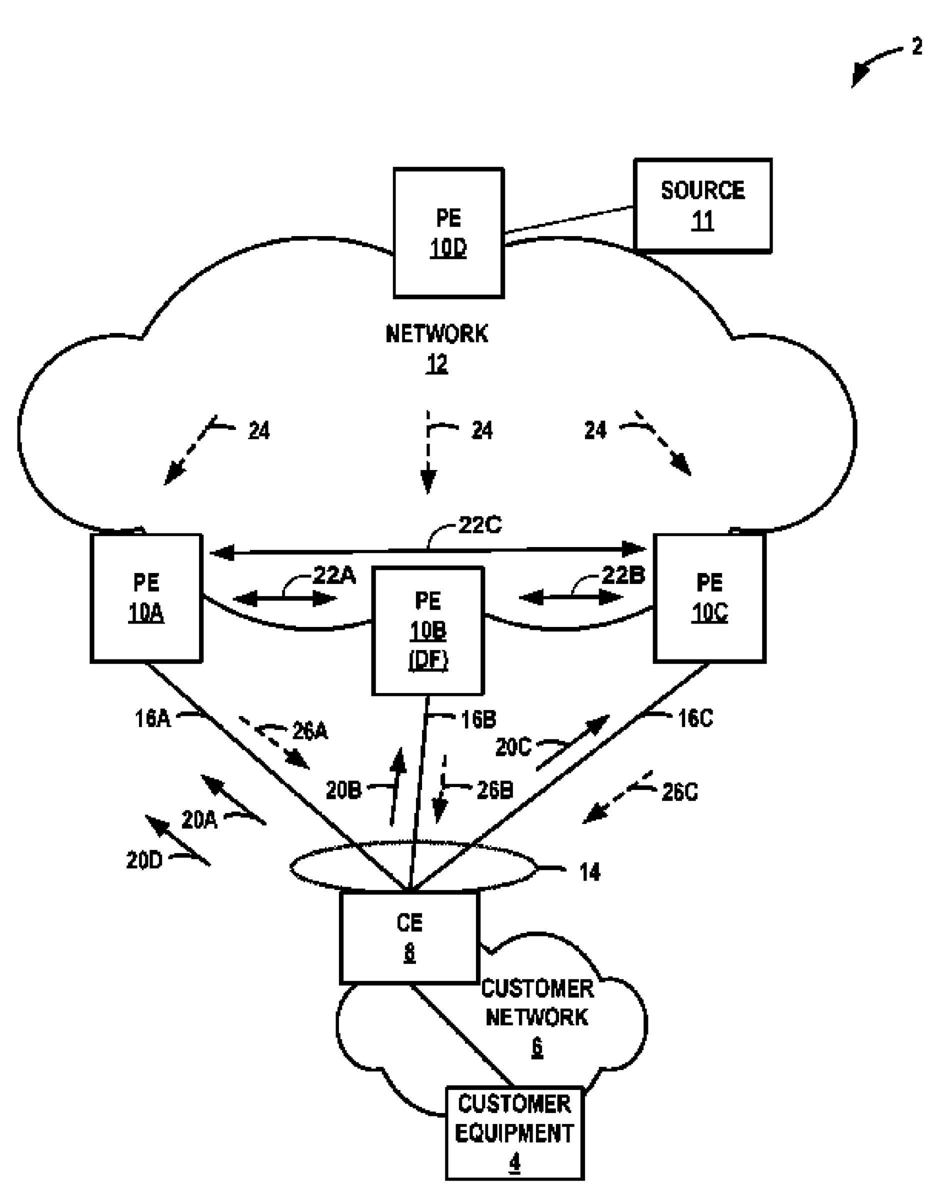
(57) **ABSTRACT**

In general, techniques are described for load-balancing responsibility for forwarding of multicast traffic into an active-active Ethernet segment between two or more multi-homed provider edge (PE) routers in an Ethernet Virtual Private Network (EVPN). In one example, a PE router may receive an Internet Group Management Protocol (IGMP) join report for a multicast group. The PE router may send join synch routes used to synchronize the join report for the multicast group across the Ethernet segment. The PE router may deterministically determine whether the PE router is configured to be an elected multicast forwarder for one of a plurality of multicast groups. If the PE router is elected a multicast forwarder, the PE router may configure a forwarding state of the PE router to ignore a designated forwarder calculation and to forward the multicast traffic into the Ethernet segment regardless of whether the PE router is a designated forwarder.

20 Claims, 5 Drawing Sheets



(51) **Int. Cl.**
H04L 29/06 (2006.01)
G06F 9/54 (2006.01)
H04L 12/803 (2013.01)
H04L 12/18 (2006.01)

(52) **U.S. Cl.**
CPC ***H04L 65/4076*** (2013.01); *H04L 12/18* (2013.01); *H04L 47/125* (2013.01)

(58) **Field of Classification Search**
CPC H04L 12/4633; H04L 45/02; H04L 45/28; H04L 45/586; H04L 49/70
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

9,461,840	B2 *	10/2016	Chatwani	H04L 12/4625
2006/0268869	A1	11/2006	Boers et al.	
2012/0014386	A1 *	1/2012	Xiong	H04L 29/12028 370/392
2012/0033668	A1 *	2/2012	Humphries	H04L 12/185 370/390
2012/0033669	A1 *	2/2012	Mohandas	H04L 45/245 370/392
2014/0226531	A1	8/2014	Farkas et al.	
2014/0269710	A1 *	9/2014	Sundaram	H04L 45/302 370/392

OTHER PUBLICATIONS

Fenner, "Internet Group Management Protocol, Version 2," Network Working Group; RFC 2236, Nov. 1997, 24 pp.
Cain et al., "Internet Group Management Protocol, Version 3," Network Working Group; RFC 3376, Oct. 2002, 53 pp.
Holbrook et al., "Using Internet Group Management Protocol Version 3 (IGMPv3) and Multicast Listener Discovery Protocol Version 2 (MLDv2) for Source-Specific Multicast," Network Working Group; RFC 4604, Aug. 2006, 11 pp.
Sajassi, et al., "IGMP and MLD Proxy for EVPN," BESS Working Group, Internet-Draft, Mar. 27, 2017, 25 pp.
Sajassi, et al., "IGMP and MLD Proxy for EVPN," BESS Working Group, Internet-Draft, Oct. 17, 2015, 13 pp.
Deering, "Host Extensions for IP Mutlicasting" Network Working Group; RFC 1112, Aug. 1989, 16 pp.
Lin et al., "EVPN Inter-Subnet Multicast Forwarding, draft-Lin-bess-evpn-irb-mcast-00.txt," BESS, Internet-Draft, Apr. 3, 2015, 8 pp.
Extended Search Report from counterpart European Application No. 18164348.7, dated Oct. 4, 2018, 13 pp.

* cited by examiner

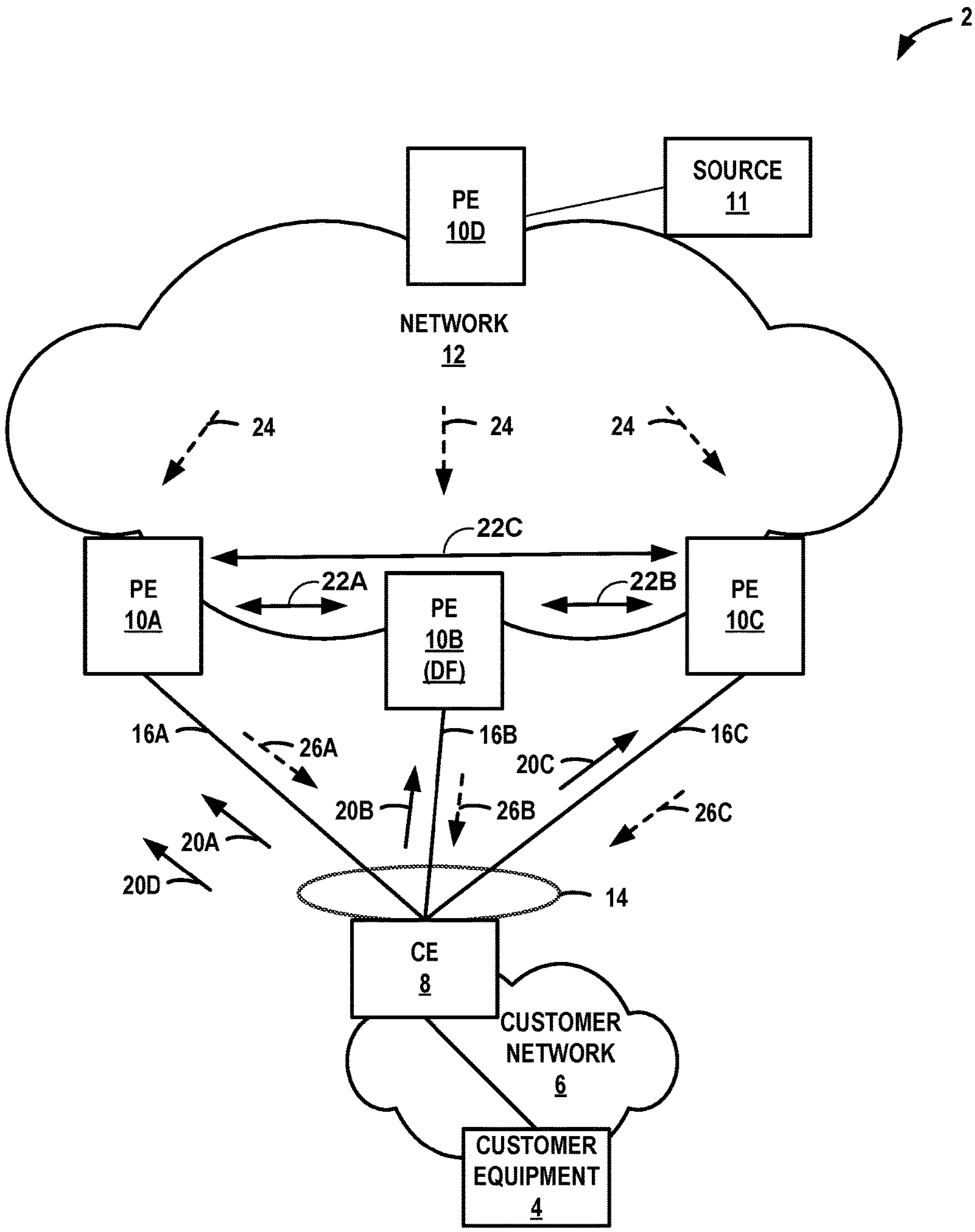
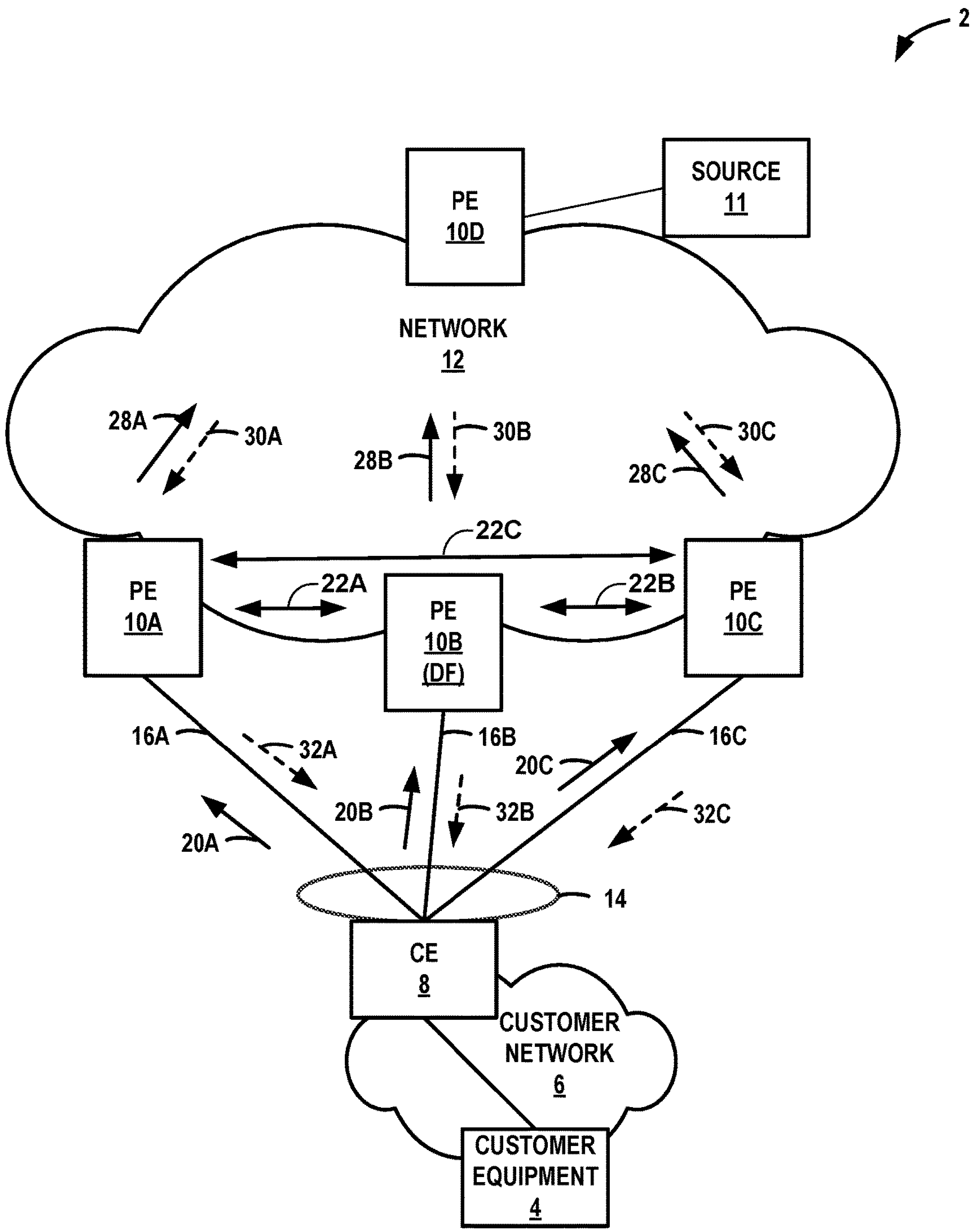

2
PE
10D
SOURCE
11
NETWORK
12
24
24
24
22C
PE
10A
22A
PE
10B
(DF)
22B
PE
10C
16A
26A
16B
20C
16C
20B
26B
26C
20A
20D
14
CE
8
CUSTOMER
NETWORK
6
CUSTOMER
EQUIPMENT
4

FIG. 1


2
PE
10D
SOURCE
11
NETWORK
12
28A
30A
28B
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28C
30C
22C
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22B
PE
10A
PE
10B
(DF)
PE
10C
16A
32A
16B
20C
16C
20B
32B
32C
20A
14
CE
8
CUSTOMER
NETWORK
6
CUSTOMER
EQUIPMENT
4

FIG. 2

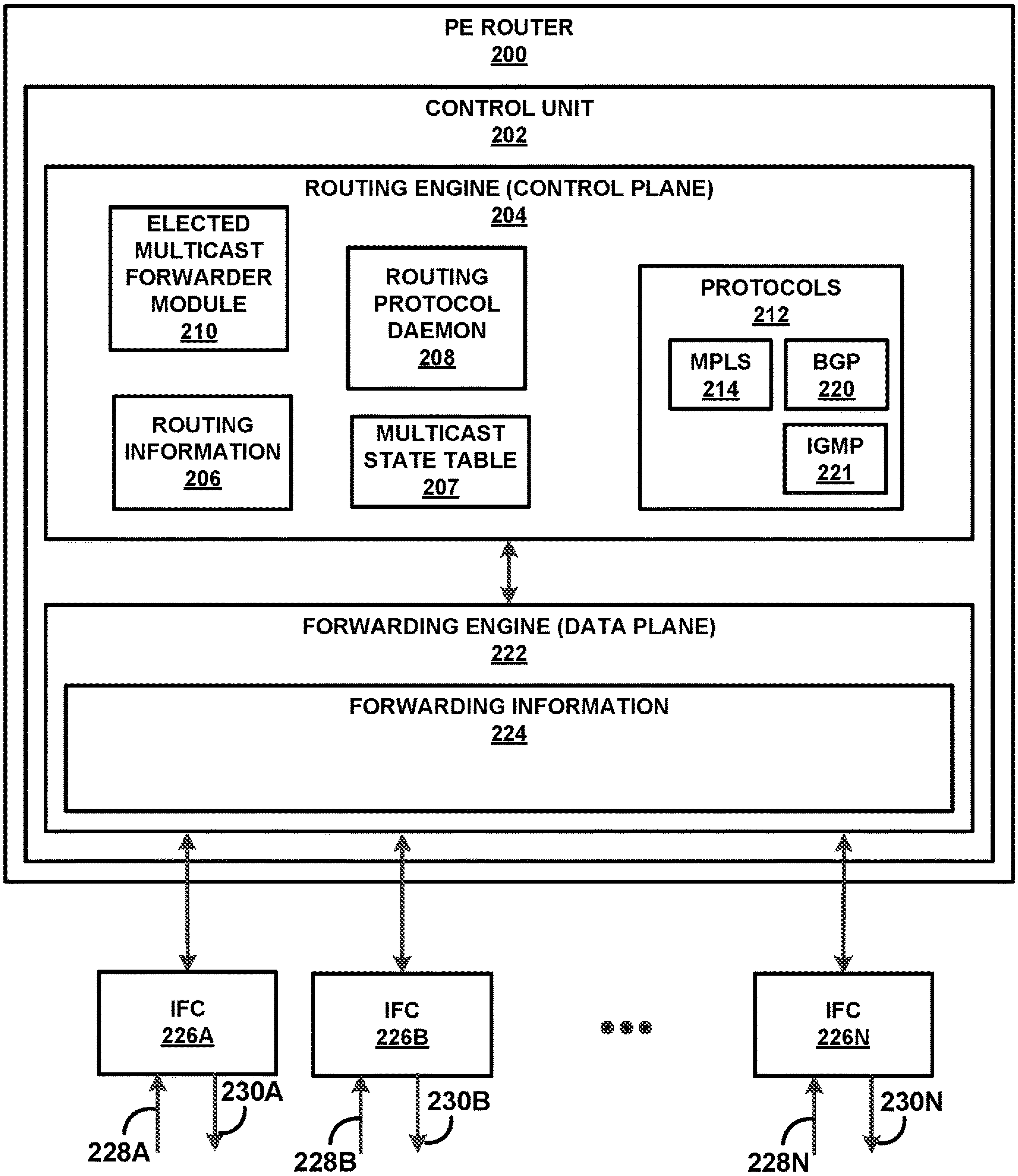
PE ROUTER
200
CONTROL UNIT
202
ROUTING ENGINE (CONTROL PLANE)
204
ELECTED MULTICAST FORWARDER MODULE
210
ROUTING PROTOCOL DAEMON
208
PROTOCOLS
212
MPLS
214
BGP
220
IGMP
221
ROUTING INFORMATION
206
MULTICAST STATE TABLE
207
FORWARDING ENGINE (DATA PLANE)
222
FORWARDING INFORMATION
224
IFC
226A
IFC
226B
IFC
226N
230A
228A
230B
228B
230N
228N

FIG. 3

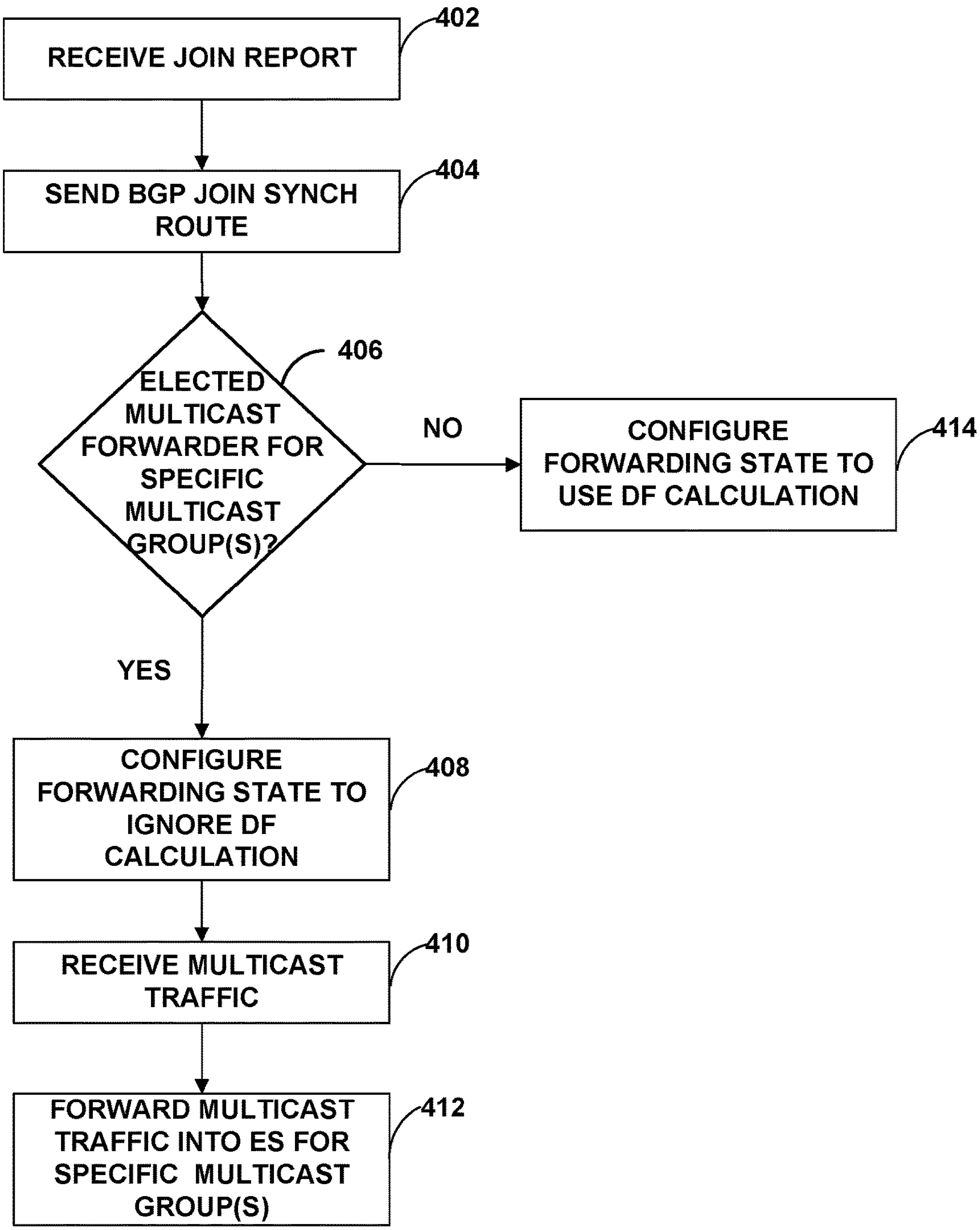
402
RECEIVE JOIN REPORT
404
SEND BGP JOIN SYNCH ROUTE
406
ELECTED MULTICAST FORWARDER FOR SPECIFIC MULTICAST GROUP(S)?
NO
CONFIGURE FORWARDING STATE TO USE DF CALCULATION
414
YES
CONFIGURE FORWARDING STATE TO IGNORE DF CALCULATION
408
RECEIVE MULTICAST TRAFFIC
410
FORWARD MULTICAST TRAFFIC INTO ES FOR SPECIFIC MULTICAST GROUP(S)
412

FIG. 4

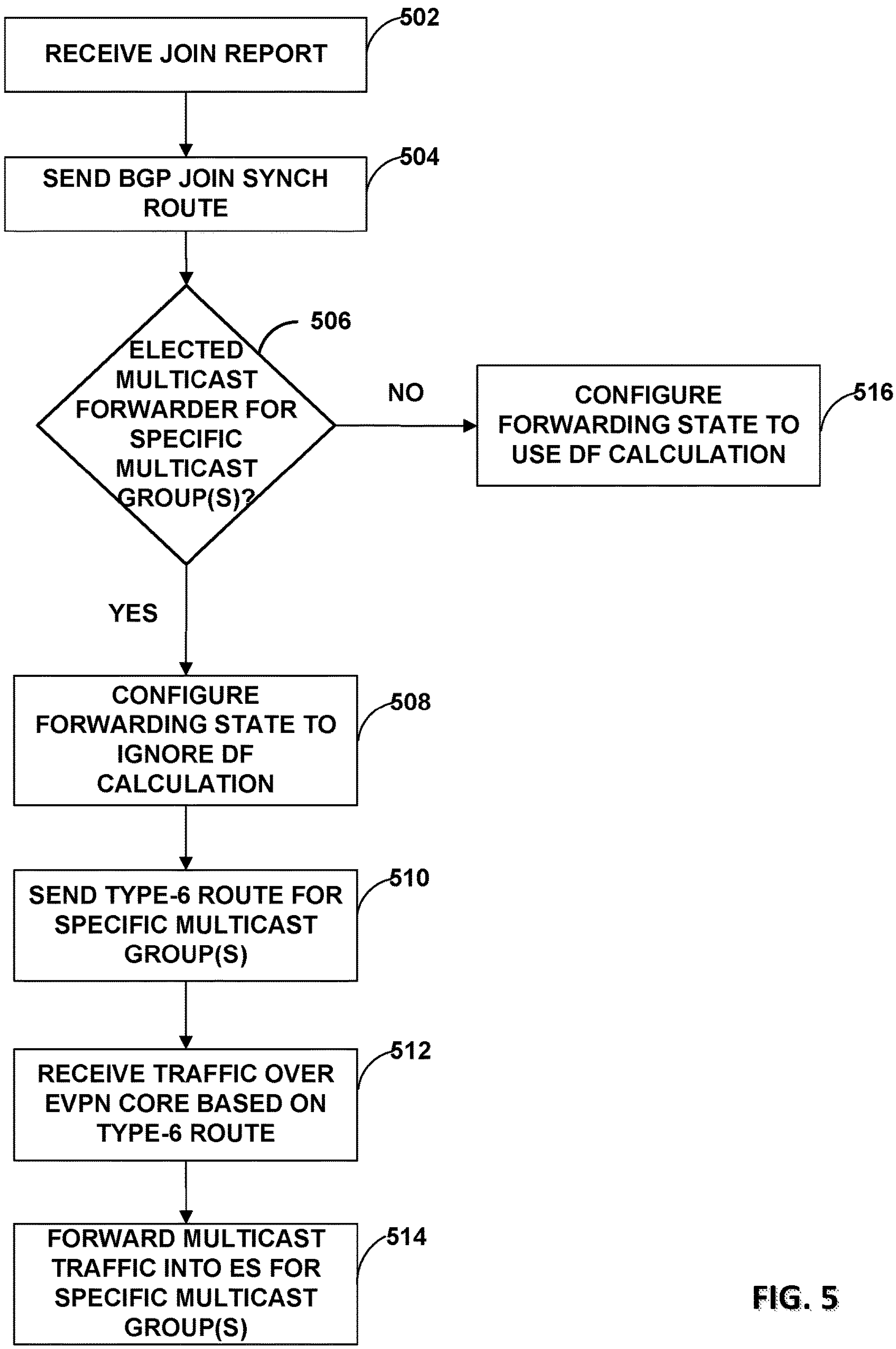
502
RECEIVE JOIN REPORT
504
SEND BGP JOIN SYNCH ROUTE
506
ELECTED MULTICAST FORWARDER FOR SPECIFIC MULTICAST GROUP(S)?
NO
516
CONFIGURE FORWARDING STATE TO USE DF CALCULATION
YES
508
CONFIGURE FORWARDING STATE TO IGNORE DF CALCULATION
510
SEND TYPE-6 ROUTE FOR SPECIFIC MULTICAST GROUP(S)
512
RECEIVE TRAFFIC OVER EVPN CORE BASED ON TYPE-6 ROUTE
514
FORWARD MULTICAST TRAFFIC INTO ES FOR SPECIFIC MULTICAST GROUP(S)

FIG. 5

MULTICAST LOAD BALANCING IN MULTIHOMING EVPN NETWORKS

This application claims the benefit of Indian Provisional Patent Application No. 201741011652, filed on Mar. 31, 2017, the entire content of which is incorporated herein by reference.

TECHNICAL FIELD

The invention relates to computer networks and, more particularly, Ethernet Virtual Private Networks (EVPNs).

BACKGROUND

A computer network is a collection of interconnected computing devices that can exchange data and share resources. Example computing devices include routers, switches or other layer two (L2) devices that operate within the second layer of the Open Systems Interconnection (OSI) reference model, i.e., the data link layer, and routers or other layer three (L3) devices that operate within the third layer of the OSI reference model, i.e., the network layer. Network devices within computer networks often include a control unit that provides control plane functionality for the network device and forwarding components for routing or switching data units.

An Ethernet Virtual Private Network ("EVPN") may be used to extend two or more remote L2 customer networks through an intermediate L3 network (usually referred to as a "provider network"), in a transparent manner, i.e., as if the intermediate L3 network does not exist. In particular, the EVPN transports L2 communications, such as Ethernet packets or "frames," between customer networks via the intermediate L3 network. In a typical configuration, provider edge ("PE") network devices (e.g., routers and/or switches) coupled to the customer edge ("CE") network devices of the customer networks define label switched paths (LSPs) within the provider network to carry encapsulated L2 communications as if these customer networks were directly attached to the same local area network (LAN). In some configurations, the PE devices may also be connected by an IP infrastructure in which case IP/GRE tunneling or other IP tunneling can be used between the network devices.

SUMMARY

In general, the disclosure describes techniques for load-balancing responsibility for forwarding multicast traffic into an active-active Ethernet segment (ES) between two or more multi-homed provider edge (PE) routers and a customer edge (CE) router in an Ethernet Virtual Private Network (EVPN).

For example, in the EVPN, a CE router is often multi-homed to two or more PE routers via an ES that appears as a link aggregation group (LAG) to the CE router. In such situations, a first one of the PE routers typically receives a join request for a multicast group from the CE router, and sends a join synch route to the other PE routers on the ES to synchronize a multicast state for the multicast group. According to the disclosed techniques and unlike conventional techniques, each of the PE routers may deterministically determine whether the PE router is to be configured as an elected multicast forwarder for forwarding multicast traffic of the multicast group to the CE router regardless of which of the PE routers is a designated forwarder (DF) or non-designated forwarder (non-DF) for the Ethernet segment. The PE router of the multi-homing PEs that is determined to be the multicast forwarder for the specific multicast group requested by the join proceeds to forward multicast traffic for that specific group into the active-active Ethernet segment regardless of the particular PE router that has been elected designated forwarder for the specific Ethernet segment.

In one example, a method includes receiving, by a provider edge (PE) router of a plurality of PE routers configured with an Ethernet Virtual Private Network (EVPN) instance reachable by an Ethernet segment connecting the plurality of PE devices to a customer edge (CE) router that is multi-homed to the plurality of PE routers over the Ethernet segment, an Internet Group Management Protocol (IGMP) join report for a multicast group. The method also includes sending, by the PE router and to the plurality of PE routers, one or more Border Gateway Protocol (BGP) join synch routes used to synchronize the IGMP join report for the multicast group across the Ethernet segment. The method also includes deterministically determining, by the PE router, whether the PE router is configured to be an elected multicast forwarder for at least one of a plurality of multicast groups. The method also includes in response to determining that the PE router is configured to be the elected multicast forwarder for the one of the plurality of multicast groups, configuring, by the PE router, a forwarding state of the PE router to forward multicast traffic for the one of the plurality of multicast groups into the Ethernet segment and to ignore a designated forwarder election for the Ethernet segment. The method also includes receiving, by the PE router, multicast traffic from an ingress PE router of the plurality of PE routers. The method also includes forwarding, by the PE router, the multicast traffic into the Ethernet segment for the one of the plurality of multicast groups.

In another example, a provider edge (PE) router includes: a memory; and one or more processors operably coupled to the memory, wherein the one or more processors and memory are configured to: receive configuration data configuring the PE router with an Ethernet Virtual Private Network (EVPN) instance reachable by an Ethernet segment connecting a plurality of PE devices, including the PE router, to a customer edge (CE) router that is multi-homed to the plurality of PE routers over the Ethernet segment; receive an Internet Group Management Protocol (IGMP) join report for a multicast group; send, to the plurality of PE routers, one or more Border Gateway Protocol (BGP) join synch routes used to synchronize the IGMP join report for the multicast group across the Ethernet segment; deterministically determine whether the PE router is configured to be an elected multicast forwarder for one of a plurality of multicast groups; in response to determining that the PE router is configured to be the elected multicast forwarder for the one of the plurality of multicast groups, configure a forwarding state of the PE router to forward multicast traffic for the one of the plurality of multicast groups into the Ethernet segment and to ignore a designated forwarder election for the Ethernet segment; receive the multicast traffic from an ingress PE router of the plurality of PE routers; and forward the multicast traffic into the Ethernet segment for the one of the plurality of multicast groups.

In another example, a computer-readable storage medium comprising instructions for causing one or more programmable processors to: receive configuration data configuring the PE router with an Ethernet Virtual Private Network (EVPN) instance reachable by an Ethernet segment connecting a plurality of PE devices, including the PE router, to a customer edge (CE) router that is multi-homed to the

plurality of PE routers over the Ethernet segment receive an Internet Group Management Protocol (IGMP) join report for a multicast group; send, to the plurality of PE routers, one or more Border Gateway Protocol (BGP) join synch routes used to synchronize the IGMP join report for the multicast group across the Ethernet segment; deterministically determine whether the PE router is configured to be an elected multicast forwarder for one of a plurality of multicast groups; in response to determining that the PE router is configured to be the elected multicast forwarder for the one of the plurality of multicast groups, configure a forwarding state of the PE router to forward multicast traffic for the one of the plurality of multicast groups into the Ethernet segment and to ignore a designated forwarder election for the Ethernet segment; receive the multicast traffic from an ingress PE router of the plurality of PE routers; and forward the multicast traffic into the Ethernet segment for the one of the plurality of multicast groups.

The details of one or more aspects of the techniques are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the techniques of this disclosure will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a block diagram illustrating an example network system for performing load-balancing responsibility for forwarding of multicast traffic into an active-active Ethernet segment between two or more multi-homed provider edge routers in an Ethernet Virtual Private Network, in accordance with the techniques described in this disclosure.

FIG. **2** is a block diagram illustrating another example network system for performing load-balancing responsibility for forwarding of multicast traffic into an active-active Ethernet segment between two or more multi-homed provider edge routers in an Ethernet Virtual Private Network, in accordance with the techniques described in this disclosure.

FIG. **3** is a block diagram illustrating an example of a provider edge router, in accordance with the techniques described in this disclosure.

FIG. **4** is a flowchart illustrating an example operation of a provider edge router, in accordance with the techniques described in this disclosure.

FIG. **5** is a flowchart illustrating another example operation of a provider edge router, in accordance with the techniques described in this disclosure.

Like reference characters denote like elements throughout the figures and text.

DETAILED DESCRIPTION

FIG. **1** is a block diagram illustrating an example network system **2** for performing load-balancing responsibility for forwarding of multicast traffic into an active-active Ethernet segment between two or more multi-homed provider edge (PE) routers in an Ethernet Virtual Private Network (EVPN), in accordance with the techniques described in this disclosure.

As shown in FIG. **1**, network system **2** includes a customer network **6** and a service provider network **12** (alternatively referred to herein as the "EVPN core **12**") configured to host an EVPN core to connect customer network **6** to other remote customer networks or other network resources (not shown in FIG. **1**). PE routers **10**A-**10**C ("PE routers **10**") of service provider network **12** provide customer equipment **4** associated with customer network **6** with access to service provider network **12** via CE router **8**. Communication links **16**A-**16**C ("communication links **16**") may be Ethernet, Asynchronous Transfer Mode (ATM), or any other suitable network connections. The configuration of network system **2** illustrated in FIG. **1** is merely an example. For example, an enterprise network system may include more than one customer network. Nonetheless, for ease of description, only a single customer network **6** is illustrated in FIG. **1**.

PE routers **10** and CE router **8** may each represent a router in the example of FIG. **1**. However, techniques of the disclosure may be implemented using switches or other suitable network devices that participate in a L2 virtual private network ("L2VPN") service, such as an EVPN. Customer network **6** may be a network for geographically separated sites of an enterprise. Customer network **6** includes customer equipment **4**, such as, one or more non-edge switches, routers, hubs, gateways, security devices, such as firewalls, intrusion detection, and/or intrusion prevention devices, servers, computer terminals, laptops, printers, databases, wireless mobile devices such as cellular phones or personal digital assistants, wireless access points, bridges, cable modems, application accelerators, or other network devices.

Although additional network devices are not shown for ease of explanation, it should be understood that network system **2** may comprise additional network and/or computing devices such as, for example, one or more additional switches, routers, hubs, gateways, security devices such as firewalls, intrusion detection, and/or intrusion prevention devices, servers, computer terminals, laptops, printers, databases, wireless mobile devices such as cellular phones or personal digital assistants, wireless access points, bridges, cable modems, application accelerators, or other network devices. Further, service provider network **12** may couple to one or more computer networks not depicted in FIG. **1**. Moreover, although the elements of network system **2** are illustrated as being directly coupled, it should be understood that one or more additional network elements may be included along any of the illustrated links **16**A-**16**C, such that the network elements of system **2** are not directly coupled.

Service provider network **12** represents a publicly accessible computer network that is owned and operated by a service provider, which is usually a large telecommunications entity or corporation. Service provider network **12** may be an L3 computer network, where reference to a layer followed by a number refers to a corresponding layer in the OSI model. Service provider network **12** is an L3 network in the sense that it natively supports L3 operations as described in the OSI model. Common L3 operations include those performed in accordance with L3 protocols, such as the Internet protocol (IP). L3 is also known as a "network layer" in the OSI model and the term L3 may be used interchangeably with the phrase "network layer" throughout this disclosure.

Service provider network **12** typically provides a number of residential and business services, including residential and business class data services (which are often referred to as "Internet services" in that these data services permit access to the collection of publicly accessible networks referred to as the Internet), residential and business class telephone and/or voice services, and residential and business class television services. One such business data service offered by service provider network **12** includes EVPN service. For example, an EVPN is a service that provides a form of L2 connectivity across an intermediate L3 network, such as service provider network **12**, to interconnect two L2 customer networks, such as customer network **6** and another remote customer network (not shown), that are usually located in two different geographic areas. Often, an EVPN is transparent to the customer networks in that these customer networks are not aware of the intervening intermediate service provider network and instead act and operate as if these two customer networks were directly connected and formed a single L2 network. In this way, an EVPN enables a form of a transparent LAN connection between two geographically distant customer sites that each operates an L2 network and, for this reason, EVPN may also be referred to as a "transparent LAN service."

An EVPN may operate over a Multi-Protocol Label Switching (MPLS) configured network and use MPLS labels to forward network traffic accordingly. MPLS is a mechanism used to engineer traffic patterns within IP networks according to the routing information maintained by the routers in the networks. By utilizing MPLS protocols, such as Label Distribution protocol (LDP) or Resource Reservation Protocol with Traffic Engineering extensions (RSVP-TE), a source device can request a path through a network to a destination device, i.e., a Label Switched Path (LSP). An LSP defines a distinct path through the network to carry MPLS packets from the source device to a destination device. Using an MPLS protocol, each router along an LSP allocates a label and propagates the label to the closest upstream router along the path. Routers along the path add or remove the labels and perform other MPLS operations to forward the MPLS packets along the established path. Additional information with respect to the EVPN protocol is described in "BGP MPLS-Based Ethernet VPN," RFC 7432, Internet Engineering Task Force (IETF), February 2015, the entire contents of which is incorporated herein by reference.

To configure an EVPN, a network operator of service provider network **12** configures, via configuration or management interfaces, various devices included within service provider network **12** that interface with L2 customer network **6**. The EVPN configuration may include an EVPN instance ("EVI"), which comprises one or more broadcast domains. The EVPN instance is configured within service provider network **12** for customer network **6** to enable customer equipment **4** within customer network **6** to communicate with other customer equipment via the EVI as if the customer equipment were directly connected via an L2 network. In some examples, EVI may be associated with a virtual routing and forwarding instance ("VRF") on a PE router, such as any of PE routers **10**A-**10**C. Consequently, multiple EVIs may be configured on PE routers **10**A-**10**C for an Ethernet segment, e.g., Ethernet segment **14**, each of the EVIs providing a separate, logical L2 forwarding domain. In this way, multiple EVIs may be configured that each includes one or more of PE routers **10**A-**10**C.

For example, Ethernet segment **14** may comprise a first EVI that includes PE routers **10**A-**10**C, and a second EVI that includes only PE routers **10**A and **10**B. In some examples, Ethernet Tags are then used to identify a particular broadcast domain, e.g., a VLAN, in an EVI. A PE router may advertise a unique EVPN label per <Ethernet Segment Identifier (ESI), Ethernet Tag> combination. This label assignment methodology is referred to as a per-<ESI, Ethernet Tag> label assignment. Alternatively, a PE router may advertise a unique EVPN label per media access control (MAC) address. In still another example, a PE router may advertise the same single EVPN label for all MAC addresses in a given EVI. This label assignment methodology is referred to as a per EVI label assignment.

In one example, to operate Ethernet segment **14** in an active-active Ethernet segment, PE routers **10**A-**10**C perform an EVPN designated forwarder election for multi-homed Ethernet segment **14**. In EVPN, a CE router is said to be "multi-homed" when it is coupled to two or more physically different PE routers on the same EVI when the PE routers are resident on the same physical Ethernet segment. For example, CE router **8** is coupled to PE routers **10**A-**10**C via links **16**A-**16**C, respectively, where PE routers **10**A-**10**C are capable of providing L2 customer network **6** access to EVPN via CE router **8**. Multi-homed networks are often employed by network operators so as to improve access to EVPN provided by service provider network **12** should a failure in one of links **16**A-**16**C occur. When a CE router is multi-homed to two or more PE routers, either one or all of the multi-homed PE routers are used to reach the customer site depending on the multi-homing mode of operation. The PE router that assumes the primary role for forwarding broadcast, unicast, and/or multicast (BUM) traffic to the CE router is called the designated forwarder ("DF" or "DF router"). In a typical EVPN configuration, the multi-homing PE routers participate in DF election for each Ethernet segment identifier (ESI) for Ethernet segment **14**.

In the example of FIG. **1**, when providing EVPN service to customer network **6**, PE routers **10**A-**10**C and CE router **8** typically perform MAC address learning to efficiently forward L2 network communications in service provider network **12**. That is, as PE routers **10**A-**10**C and CE router **8** forward Ethernet frames, the routers learn L2 state information for the L2 network, including MAC addressing information for customer equipment **4** within the network and the physical ports through which customer equipment **4** are reachable. PE routers **10**A-**10**C and CE router **8** typically store the MAC addressing information in MAC tables associated with respective interfaces. When forwarding an individual Ethernet frame received on one interface, a router typically broadcasts the Ethernet frame to all other interfaces associated with the EVPN unless the router has previously learned the specific interface through which the destination MAC address specified in the Ethernet frame is reachable. In this case, the router forwards a single copy of the Ethernet frame out the associated interface.

As further described below, as PE routers **10**A-**10**C learn the MAC address for customer equipment **4** reachable through local attachment circuits, PE routers **10**A-**10**C utilize MAC address route advertisements of an L3 routing protocol, e.g., Border Gateway Protocol (BGP) to share the learned MAC addresses and to provide an indication that the MAC addresses are reachable through the particular PE router that is issuing the route advertisement. In the EVPN implemented using PE routers **10**A-**10**C for a given EVI, each of PE routers **10**A-**10**C advertises the locally learned MAC addresses to other PE routers **10** using a BGP router advertisement, also referred to herein as a "MAC route" or a "MAC advertisement route." A MAC advertisement route typically specifies an individual MAC address of customer equipment **4** along with additional forwarding information such as a route descriptor, route target, layer 2 segment identifier, MPLS label, etc. In this way, PE routers **10** use BGP to advertise and share the MAC addresses learned when forwarding layer two communications associated with the EVPN. Accordingly, PE routers **10** may perform both local learning and remote learning of MAC addresses.

Additional example information with respect to BGP is described in "BGP MPLS-Based Ethernet VPN," RFC 7432, as referenced above.

In the example of FIG. **1**, source device **11** operates as a source for multicast traffic **24** to be delivered through to customer equipment **4** by way of the EVPN. In general, multicast network traffic is associated with specific multicast groups. More specifically, multicast traffic is typically designated by a unique combination of a particular multicast group and a particular source for the multicast group. For example, multicast network traffic **24**, such as a particular multicast stream of content, may be uniquely designated with a (Source, Group), i.e., (S, G), label to designate a source of the traffic and a multicast group to which the traffic belongs. PE routers **10**A-**10**C of Ethernet segment **14** may use Internet Group Management Protocol (IGMP) to communicate multicast group membership information to neighboring routers to establish a multicast group state for routing purposes. For example, PE routers **10**A-**10**C of Ethernet segment **14** may use the IGMP protocol to receive Join and Leave messages from hosts or receivers, e.g., customer equipment **4**, connected to CE router **8**. Upon receiving, from the hosts, a notification to subscribe in the membership of a specific multicast group, one of PE routers **10**A-**10**C forwards this information to the other PE routers **10** of Ethernet segment **14** over the EVPN using Ethernet Multicast Source Group Route Network Layer Reachability Information (NLRI). The NLRI also tracks the IGMP protocol version of a recipient as well as any source filtering for a given group membership. Thus, PE routers **10**A-**10**C of Ethernet segment **14** may be informed of the group membership information and route multicast network traffic of the requested multicast group to CE device **8** based on the (S, G) label of the multicast traffic. Additional details of IGMP are provided within "Host Extensions for IP Multicasting," RFC 1112, Internet Engineering Task Force (IETF), August 1989; "Internet Group Messaging Protocol, Version 2," RFC 2236, Internet Engineering Task Force (IETF), November 1997; "Internet Group Management Protocol, Version 3," RFC 3376, Internet Engineering Task Force (IETF), October 2002; and "Using Internet Group Management Protocol Version 3 (IGMPv3) and Multicast Listener Discovery Protocol Version 2 (MLDv2) for Source-Specific Multicast," RFC 4604, Internet Engineering Task Force (IETF), August 2006; and "IGMP and MLD Proxy for EVPN," draft-saassi-bess-evpn-igmp-mld-proxy-01, Oct. 28, 2016, the entire contents of each of which is incorporated herein by reference.

In the example of FIG. **1**, Ethernet segment **14** is configured to operate in all-active redundancy mode. In all-active redundancy mode, each of PE routers **10**A-**10**C attached to Ethernet segment **14** is configured to forward traffic to and from customer network **6**. While operating in this mode, any of PE routers **10**A-**10**C may receive traffic from customer network **6**, and may receive from CE router **8** a respective one of IGMP join reports **20**A-**20**C (collectively, "IGMP join reports **20**" or "IGMP membership reports **20**"). Upon receiving the respective one of IGMP join reports **20**, each of PE routers **10**A-**10**C attached to Ethernet segment **14** communicates the multicast group membership information to neighboring PE routers such that the neighboring PE routers may synchronize IGMP Join and Leave Group state across Ethernet segment **14**. The IGMP Join and Leave Group state may be represented as (x, G), where "x" may be either any source (*) or a particular source (S), for each EVI on Ethernet segment **14**, and "G" is a multicast group. For example, PE router **10**A may receive IGMP join report **20**A which notifies PE router **10**A the membership for which customer equipment **4** is subscribing, e.g., a first multicast group. PE router **10**A may communicate the information from IGMP join report **20**A to PE routers **10**B and **10**C via an IGMP join synch route, as further described below. PE routers **10**B and **10**C may receive the IGMP join synch route and synchronize the IGMP join group state such that PE routers **10**A-**10**C may forward multicast traffic **24** received over the EVPN core **12** to the corresponding multicast group. By synchronizing IGMP Join and Leave Group state, the DF, e.g., router **10**B, for a particular Ethernet segment, EVPN Instance, and Bridge Domain (BD) (hereinafter, "[ES, EVI, DB]") may correctly advertise or withdraw routes to the EVPN core for the multicast traffic for that multicast group.

PE routers **10** use control plane signaling with different route types (herein referred to as "EVPN routes") to implement the EVPN service in service provider network **12**. EVPN defines BGP NLRI, and in particular, defines different route types. The NLRI is carried in BGP using BGP Multiprotocol Extensions. EVPN route types include but are not limited to Ethernet Auto-Discovery (AD) per Ethernet segment routes (Type-1), MAC advertisement routes (Type-2), Inclusive Multicast Ethernet Tag (IMET) (Type-3), Ethernet Segment routes (Type-4), and BGP join synch routes (Type-7).

PE devices **10**A-**10**D may advertise Ethernet AD routes (Type-1) specifying the relevant ESI for the Ethernet segment for the EVI. That is, each of PEs **10** may advertise an Ethernet AD route per Ethernet segment to advertise reachability of the PE device for the Ethernet segment. An Ethernet AD route advertised by each of PE devices **10**A-**10**D specifies a Route Distinguisher (RD) (which may include, e.g., an Internet Protocol (IP) address of the originating PE), ESI, Ethernet Tag Identifier, and MPLS label, for example. Per RFC 7432, the Ethernet AD route advertisement may also include an ESI Label extended community attribute to enable split-horizon procedures for multi-homed sites. Because each of Ethernet segments **14** is multi-homed to multiple PEs **10**, the respective ESIs for Ethernet segments **14** are non-zero and unique within system **2**.

As described above, each of PEs **10** may advertise MAC advertisement routes (Type-2) to describe a MAC address state. That is, each of PEs **10** may exchange MAC advertisement routes describing the reachability of MAC addresses for an Ethernet segment that was learned by the PE device. A MAC advertisement route advertised by each of PE devices **10**A-**10**D specifies a RD, ESI, Ethernet Tag Identifier, MAC address of a host device (and/or IP address of the host device), and MPLS label, for example.

To enable PEs **10** connected to the same Ethernet segment **14** to automatically discover one another and for purposes of Designated Forwarder election per ES, each PE of PEs **10** advertises an Ethernet Segment route (Type-4) for each of the Ethernet segments multi-homed by the PE. For example, PE **10**A advertises an Ethernet Segment route for each of Ethernet segments **14**A and **14**B. An Ethernet Segment route specifies a Route Distinguisher, Ethernet Segment Identifier, and an originating router's network address, for example.

In some examples, PE routers **10**A-**10**C may advertise a Type-7 BGP route to describe a multicast state. A Type-7 BGP route, also referred to herein as a "BGP join synch route," is used for coordinating or synchronizing a multicast join synch request amongst PE routers of an Ethernet segment. In other words, an EVPN may use a Type-7 route to coordinate the IGMP Join (x,G) state for a given EVI between each of the PE routers attached to a given ES when operating in either single or all-active redundancy mode. The Type-7 route indicates that a PE router has received an IGMP join request to join a multicast group on the ES. When one of PE routers receives an IGMP join report on an Ethernet segment from a CE router, it sends out a BGP Type 7 route with the ESI value. Each additional multi-homed PE router on the Ethernet segment imports the Type-7 route and, based on the Type-7 route, synchronizes its IGMP state.

In the example of FIG. **1**, PE routers **10** may receive IGMP join reports **20** that report the membership of customer equipment **4** with a particular multicast group. PE routers **10** may send respective Type-7 BGP join synch routes **22**A-**22**C with an ESI value to inform other PE routers on Ethernet segment **14** of the membership of customer equipment **4** with the particular multicast group.

In one example, PE router **10**A may receive IGMP join report **20**A that reports the membership of customer equipment **4** with a first multicast group. PE router **10**A may send a Type-7 BGP join synch route **22**A and **22**C with an ESI value to inform PE routers **10**B and **10**C, respectively, of the membership of customer equipment **4** with the first multicast group. PE routers **10**B and **10**C may each import the respective Type-7 BGP join synch routes and create an IGMP join state that associates customer equipment **4** with the first multicast group.

Similarly, PE routers **10**B and **10**C may each receive IGMP join reports **20**B and **20**C, respectively, that report the membership of customer equipment **4** with a second and third multicast groups, respectively. PE routers **10**B and **10**C may each send Type-7 BGP join synch routes to other PE routers of Ethernet segment **14** such that the other PE routers **10** may be informed of the membership of customer equipment **4** with the second and third multicast groups. In response to exchanging the Type-7 BGP join synch routes, each of PE routers **10**A-**10**C may create an IGMP join state for the first, second, and third multicast groups.

In the example of FIG. **1**, PE routers **10** within an EVPN may utilize a BGP NLRI, such as Inclusive Multicast Ethernet Tag (IMET) route (Type-3), to set up a path to forward and receive multicast traffic over the EVPN core. By utilizing IMET, each of PE routers **10** that span the VLAN in that EVPN instance may receive multicast traffic **24** from ingress PE router **10**D for source device **11** over the EVPN core **12**. That is, by utilizing IMET, ingress PE router **10**D may flood multicast traffic **24** to all of PE routers **10**A-**10**C over the EVPN core **12**. Additional information with respect to IMET is described in "BGP MPLS-Based Ethernet VPN," Internet Draft, draft-ietf-12vpn-evpn-11, Oct. 18, 2014, the entire contents of which is incorporated herein by reference.

In the example of FIG. **1**, PE routers **10**A-**10**C belong to Ethernet segment **14**. In this example, PE router **10**B has been elected a DF for forwarding network traffic from EVPN core **12** into Ethernet segment **14**. As such, PE router **10**B would typically be the only PE router responsible for forwarding multicast traffic **24** from the EVPN core into Ethernet segment **14** for all multicast groups. In one example, ingress PE router **10**D may, based on the IMET configuration, flood multicast traffic **24** over the EVPN core to each of PE routers **10**A-**10**C. Non-designated forwarders, e.g., PE routers **10**A and **10**C, would typically drop multicast traffic **24** that was received over the EVPN core, which would otherwise lead to wasted utilization of the EVPN core bandwidth within network **12**.

PE router **10**B, as the DF, may become overloaded from forwarding multicast traffic for all multicast groups. Although non-designated forwarders have available bandwidth, a designated forwarder configuration underutilizes the available bandwidth that may provide load-balancing for the multicast traffic.

In accordance with the techniques described herein, each of PE routers **10**A-**10**C may deterministically determine which of the PE routers is to be configured as an elected multicast forwarder for a specific multicast group regardless of which of the PE routers is a designated forwarder or non-designated forwarder for the Ethernet segment.

As noted above, PE router **10**A may receive IGMP join report **20**A in which customer equipment **4** is reporting its membership to a first multicast group, PE router **10**B may receive IGMP join report **20**B in which customer equipment **4** is reporting its membership to a second multicast group, and PE router **10**C may receive IGMP join report **20**C in which customer equipment **4** is reporting its membership to a third multicast group. Each of PE routers **10**A-**10**C may exchange Type-7 routes such that each of PE routers **10**A-**10**C may create IGMP join states to synchronize the multicast groups and EVI to which the IGMP join reports belong.

In addition to exchanging Type-7 BGP join synch routes, in accordance with the techniques described herein, each of PE routers **10**A-**10**C may additionally determine, based on a number of example techniques, whether the PE router is to be configured as an elected multicast forwarder for a specific multicast group, for example. In some examples, one example implementation of an algorithm may include dividing a network address (e.g., Internet Protocol address) for a specific multicast group by the number of multi-homed PE routers on the ESI. The result of the division may provide PE routers **10**A-**10**C an indication in which the PE routers may be elected a multicast forwarder for a particular multicast group. In some examples, an example algorithm may include applying a modulo operation to determine the remainder after a division of the multicast group network address by the number of multi-homed PE routers of Ethernet segment **14**, e.g., PE routers **10**A-**10**C, and using the remainder as an indicator of which of the PE routers **10**A-**10**C should operate as the multicast forwarder for the particular group. In some examples, the algorithm may take the join count of different groups elected by different multi-homed PE routers **10**A-**10**C by applying a hash to each of the different groups. In any event, the result of the algorithm may identify which of PE routers **10**A-**10**C is responsible for forwarding multicast traffic to a specific multicast group.

As one example, PE router **10**A may apply the algorithm and may determine, e.g., that PE router **10**A is to be configured as an elected multicast forwarder for the second multicast group. Similarly, PE routers **10**B and **10**C may each apply the algorithm and may determine, e.g., that PE routers **10**B and **10**C are to be configured as elected multicast forwarders for the third and first multicast groups, respectively.

In response to determining which PE router is elected as a multicast forwarder for a specific multicast group, each of PE routers **10**A-**10**C may configure its forwarding state to forward multicast traffic for the corresponding multicast group and to ignore the designated forwarder election algorithm. For example, in response to determining that PE router **10**A is the elected multicast forwarder for the second multicast group, PE router **10**A may configure its forwarding state to forward multicast traffic **26**A into the active-active Ethernet segment **14** for the second multicast group irrespective of being a non-designated forwarder. Likewise, PE router **10**C may configure its forwarding state to forward multicast traffic **26**C for the first multicast group irrespective of being a non-designated forwarder.

PE router **10**B may determine, based on the algorithm, that PE router **10**B is an elected multicast forwarder for the third multicast group. PE router **10**B may configure its forwarding state to ignore the designated forwarder election algorithm and forward multicast traffic **26**B for only the third multicast group regardless of being a designated forwarder for PE routers **10**A-**10**C. For a PE router that is not an elected multicast forwarder for a specific multicast group, the PE router will not forward the traffic toward CE router **8** to avoid sending duplicate traffic.

In this way, each of PE routers **10**A-**10**C of Ethernet segment **14** may be elected multicast forwarder for a specific multicast group such that the PE routers may forward the multicast traffic regardless of which PE router is a designated forwarder or non-designated forwarder. By electing multicast forwarders for specific multicast groups, multicast traffic may be load-balanced across the PE routers of a multi-homed environment.

In some examples, in a network implementing IMET, PE routers **10** may exchange extended IMET routes (Type-3) including at least a multicast identifier. Ingress PE router **10**D may configure multicast traffic to include a multicast identifier as a multicast label. Upon receiving the extended Type-3 route, PE routers **10** may determine from the extended IMET route including the multicast identifier that the traffic is identified as multicast traffic. In one example, the IMET route may be extended to include a Default Gateway Extended Community including a multicast identifier that may be used to indicate a packet type as multicast. Additional information with respect to the Default Gateway Extended Community is described in "BGP MPLS-Based Ethernet VPN," RFC 7432, as referenced above.

In some examples, PE router **10**A may receive a new IGMP join report **20**D for an additional multicast group. PE router **10**A may determine whether PE router **10**A has the capacity to forward traffic for the additional multicast group. If PE router **10**A determines that it does not have the capacity to send multicast traffic for the additional multicast group, PE router **10**A may configure, e.g., an extended Type-7 route to inform other PE routers **10** to exclude PE router **10**A from being elected as a multicast forwarder for the additional multicast group. In some examples, a Type-7 BGP join synch route may be extended to include an EVI-RT Extended Community described in "IGMP and MLD Proxy for EVPN," Internet Draft, draft-ieft-bess-evpn-igmp-mld-proxy-00, Mar. 27, 2017, Section 7.5, to include an indication that the PE router **10**A is to be excluded from an election for a multicast forwarder. In this way, a subset of PE routers, e.g., PE routers **10**B and **10**C, of Ethernet segment **14** may receive the extended Type-7 route for which the PE routers may elect a multicast forwarder for the additional multicast group only from the subset of PE routers. In this way, PE router **10**A, is excluded from the multicast forwarder election.

FIG. **2** is a block diagram illustrating another example network system **2** for performing load-balancing responsibility for forwarding of multicast traffic into an active-active Ethernet segment between two or more multi-homed provider edge routers in an Ethernet Virtual Private Network, in accordance with the techniques described in this disclosure. Network system **2** of FIG. **2** is similar to network system **2** of FIG. **1**, except as described below.

In the example of FIG. **2**, PE routers **10** may use Selective Multicast Ethernet Tag (SMET) routes to set up a path to selectively forward and receive multicast traffic over EVPN core **12**. Unlike IMET in which ingress PE router **10**D floods multicast traffic to all PE routers **10**A-**10**C, SMET provides a carrying solution for PE routers **10** to selectively forward and receive multicast traffic from ingress PE router **10**D by sending a Type-6 route. A Type-6 route indicates that a PE router supports a SMET route. In the example of FIG. **2**, an egress PE router, e.g., any of PE routers **10**A-**10**C, may send a respective one of Type-6 routes **28**A-**28**C (collectively, "Type-6 routes **28**") that advertises a multicast source address, multicast group address, and the network address of the egress PE router, for example. In response, ingress PE router **10**D may forward multicast traffic for the specific multicast group to the egress PE router that sent the Type-6 route. For example, PE router **10**A may send Type-6 route **28**A requesting ingress PE router **10**D to forward multicast traffic for a specific multicast group. In response, ingress PE router **10**D may forward multicast traffic to PE router **10**A for the specific multicast group since PE router **10**A had sent the Type-6 route. Further examples of SMET is described in "IGMP and MLD Proxy for EVPN," Internet Draft, draft-sajassi-bess-evpn-igmp-mld-proxy-00, Oct. 17, 2015, the entire contents of which is incorporated by reference herein.

PE router **10**B, as the designated forwarder for the EVPN, typically sends multiple Type-6 routes to ingress PE router **10**D to request traffic for each of the multicast groups. Ingress PE router **10**D may, based on the SMET configuration, send multicast traffic in response to the Type-6 routes to PE router **10**B. In contrast, when non-designated forwarders, e.g., PE routers **10**A and **10**C, send Type-6 routes to request multicast traffic from ingress PE router **10**D, the non-designated forwarders may receive the multicast traffic, but may not forward the multicast traffic, which unnecessarily consumes EVPN core bandwidth.

As described in FIG. **1**, the designated forwarder may become overloaded from forwarding the multicast traffic for all multicast groups. Although non-designated forwarders have available bandwidth, a designated forwarder configuration underutilizes the available bandwidth that may provide load-balancing for the multicast traffic.

In accordance with the techniques described herein, each of PE routers **10**A-**10**C may deterministically determine whether the PE router is to be configured as an elected multicast forwarder for a specific multicast group regardless of which PE router is a designated forwarder or non-designated forwarder. In addition to determining, based on an algorithm, whether the PE router is to be elected as a multicast forwarder for a specific multicast group, the PE routers may also send respective Type-6 routes **28**A-**28**C to request multicast traffic for a specific multicast group from ingress PE router **10**D.

For example, as noted above, PE routers **10**A-**10**C may receive respective IGMP join reports **20** in which customer equipment **4** is reporting its membership to a specific multicast group. PE routers **10**A-**10**C may exchange Type-7 routes to synchronize the IGMP join states based on IGMP join reports **20** such that each of PE routers **10**A-**10**C may create IGMP join states including the first, second, and third multicast groups.

Each of PE routers **10**A-**10**C may run an algorithm to determine deterministically whether the PE router may be configured as an elected multicast forwarder for a specific multicast group. For example, PE router **10**A may run the algorithm described above and determine, e.g., that PE router **10**A is to be configured as an elected multicast forwarder for the second multicast group. PE routers **10**B and **10**C may each run the algorithm and determine, e.g., that

PE routers **10**B and **10**C are to be configured as an elected multicast forwarder for the third multicast group and the first multicast group, respectively.

If each of PE routers **10**A-**10**C determines that it is an elected multicast forwarder, each of PE routers **10**A-**10**C may configure its forwarding state to ignore a designated forwarder calculation such that the PE router may forward multicast traffic into the active-active Ethernet segment **14** for a specific multicast group regardless of which PE router is a designated forwarder or non-designated forwarder.

In the example of FIG. **2**, the PE router may additionally send a Type-6 route to request from ingress PE router **10**D to receive multicast traffic for a specific multicast group for which the PE router has been elected a multicast forwarder. For example, if PE router **10**A is determined to be an elected multicast forwarder for the second multicast group, PE router **10**A may send Type-6 route **28**A to ingress PE router **10**D to request multicast traffic for the second multicast group be sent back to PE router **10**A. In this way, the elected multicast forwarder for a specific multicast group, and not the designated forwarder (e.g., PE device **10**B), may retrieve the multicast traffic for a specific multicast group. In this way, the designated forwarder is no longer responsible for sending Type-6 routes and receiving multicast traffic for all multicast groups.

In a network implementing SMET, ingress PE router **10**D may selectively forward multicast traffic **30**A-**30**C over the EVPN core **12** to a corresponding one of PE routers **10**A-**10**C that sent a Type-6 route. Continuing the example above, ingress PE router **10**D may forward multicast traffic **30**A for the second multicast group to PE router **10**A in response to Type-6 route **28**A that was sent by PE router **10**A. Similarly, ingress PE router **10**D may forward multicast traffic **30**C for the first multicast group to PE router **10**C in response to Type-6 route **28**C that was sent by PE router **10**C. Upon receiving the multicast traffic for the second multicast group, PE routers **10**A and **10**C may, instead of dropping the multicast traffic as non-designated forwarders, forward the multicast traffic into Ethernet segment **14** for the second multicast group and the first multicast group, respectively.

Ingress PE router **10**D may also forward multicast traffic **30**B for the third multicast group to PE router **10**B in response to Type-6 route **28**B that was sent by PE router **10**B. PE router **10**B may, instead of forwarding multicast traffic for all multicast groups as a designated forwarder, forward only the multicast traffic for the third multicast group into Ethernet segment **14**. In this way, by electing multicast forwarders for specific multicast groups, multicast traffic may be load-balanced across the PE routers of a multi-homed environment.

FIG. **3** is a block diagram illustrating an example PE router **200** within an EVPN in accordance with the techniques of the disclosure. In general, PE router **200** is described with respect to any of PE routers **10**A-**10**C of FIGS. **1**-**2**. In this example, PE router **200** includes interface cards **226**A-**226**N ("IFCs **226**") that receive packets via incoming links **228**A-**228**N ("incoming links **228**") and send packets via outbound links **230**A-**230**N ("outbound links **230**"). IFCs **226** are typically coupled to links **228**, **230** via a number of interface ports (not shown). PE router **200** also includes a control unit **202** that determines routes of received packets and forwards the packets accordingly via IFCs **226**.

Control unit **202** includes a routing engine **204** and a forwarding engine **222**. Routing engine **204** operates as the control plane for PE router **200** and includes an operating system that provides a multi-tasking operating environment for execution of a number of concurrent processes. Routing engine **204**, for example, executes software instructions to implement one or more control plane networking protocols **212**. For example, protocols **212** may include one or more routing protocols, such as BGP **220**, for exchanging routing information with other routing devices and for updating routing information **206**, Multiprotocol Label Switching (MPLS) protocol **214**, and Internet Group Management Protocol (IGMP) **221**. A routing protocol daemon (RPD) **208** executes protocols **212**. Routing engine **204** further includes a multicast state table **207**. Multicast state table **207** maintains IGMP state data for a plurality of multicast groups to which PE router **200** belongs.

In addition, routing engine **204** communicates with other routers to establish and maintain an EVPN, such as the EVPN of FIG. **1**, for transporting L2 communications through an intermediate L3 network so as to logically extend an Ethernet network through the intermediate L3 network. When implementing an EVPN, L2 MAC learning may be performed in the control plane by exchanging, with remote PE devices, BGP messages containing MAC addresses. For example, routing engine **204** uses information recorded in routing information **206** to compose messages describing routing and reachability, which forwarding engine **222** sends to other PE routers **200** within the EVPN. In some examples, routing engine **204** composes such routing and reachability messages according to a routing protocol, such as BGP protocol **220**. Additional example information with respect to EVPN and the BGP protocol is described in "BGP MPLS-Based Ethernet VPN," RFC 7432, as referenced above.

Forwarding information **224** included in forwarding engine **222** may include lookup structures. Lookup structures may, given a key, such as an address, provide one or more values. In some examples, the one or more values may be one or more next hops. A next hop may be implemented as microcode, which when executed, performs one or more operations. One or more next hops may be "chained," such that a set of chained next hops perform a set of operations for respective different next hops when executed. Examples of such operations may include applying one or more services to a packet, dropping a packet, and/or forwarding a packet using an interface and/or interface identified by the one or more next hops.

Routing information **206** may describe a topology of the computer network in which PE router **200** resides, and may also include routes through the shared trees in the computer network. Routing information **206** describes various routes within the computer network, and the appropriate next hops for each route, i.e., the neighboring routing devices along each of the routes. Routing engine **204** analyzes information stored in routing information **206** and generates forwarding information for forwarding engine **222**, stored in forwarding information **224**. Forwarding information **224** may associate, for example, network destinations for certain multicast groups with specific next hops and corresponding IFCs **226** and physical output ports for output links **230**. Forwarding information **224** may be a radix tree programmed into dedicated forwarding chips, a series of tables, a complex database, a link list, a radix tree, a database, a flat file, or various other data structures.

If a PE router **200**, either the DF or a non-DF PE router, receives, on a given multi-homed Ethernet segment operating in all-active redundancy mode, an IGMP join report for (x, G), it determines the EVI to which the IGMP join report belongs. If PE router **200** does not already have a local IGMP Join (x, G) state for that EVI on that ES in the routing information **206** of PE router **200**, PE router **200** instantiates a local IGMP Join (x, G) state in multicast state table **207**, installs a BGP Type-7 route, e.g., a BGP join synch route, in routing information **206**, and advertises the BGP Type-7 route for that [ES, EVI, BD] to other PE routers on the Ethernet segment. In this example, Local IGMP Join (x, G) state refers to an IGMP Join (x, G) state that is created as the result of processing an IGMP join report for (x, G).

The BGP join synch route carries the ES-Import Route Target (RT) for the ES on which the IGMP Membership Report was received. PE router **200** issues the BGP join synch route to all PE routers attached to that ES. Thus, all PE routers attached to the ES receive the BGP join synch route, but PE routers not attached to the ES do not receive the BGP join synch route.

If a PE router **200**, either the DF or a non-DF PE router, receives a BGP join synch route from a peer PE router on a same ES, PE router **200** installs that route in routing information **206**. If PE router **200** does not already have an IGMP Join (x, G) state for that EVI on that ES, the PE router instantiates that IGMP Join (x,G) state in multicast state table **207**. In other words, the IGMP Join (x, G) state of PE router **200** is both multicast groups for which PE router has originated BGP join synch routes, as well as multicast groups for which PE router has received (and installed) BGP join synch routes. If the DF is not currently advertising (originating) a BGP join synch route for that (x, G) group in that EVI, the DF may do so now.

PE router **200** may, at configuration and startup, perform a designated forwarder election algorithm to determine an ordering (e.g., "designated forwarder ordering") with which one of PE routers, e.g., PE routers **10**A-**10**C, become the designated forwarder for one or more EVIs of Ethernet segment **14**. Each of PE routers **10**A-**10**C perform the same designated forwarder algorithm to ensure that each of PE routers **10**A-**10**C determine the same ordering. For instance, routing engine **204** of PE router **10**A may send one or more control plane messages to PE routers **10**B-**10**C. Routing engine **204**, in some examples, sends the control plane messages using a layer 3 protocol such as BGP. The control plane messages may request information from the other PE routers, such as network addresses associated with each of the PE routers.

Routing engine **204** may determine respective orderings with which PE routers **10**A-**10**C become the designated forwarder. For instance, routing engine **204** may use a hash function that takes as input, a value comprised of the network address for a given PE router and the common VLAN tag. The output of the hash function may be a hashcode for the given PE router. Routing engine **204** may generate a set of hashcodes, one hash code for each respective PE router. Routing engine **204**, in some examples, may sort the set of hashcodes in an ordering (e.g., ascending or descending). Routing engine **204** may then determine the designated forwarder is, for example, the PE router associated with the hashcode that corresponds to the smallest index of the ordering. For instance, an ordering may have an index from 0 . . . n. The smallest index of the ordering may therefore be 0.

According to the techniques of the disclosure, PE router **200** may include an elected multicast forwarder module **210** for deterministically determining whether PE router **200** may be an elected multicast forwarder for a specific multicast group. For example, elected multicast forwarder module **210** may determine, based on an algorithm, whether PE router **200** is to be elected as a multicast forwarder for a particular multicast group, and may forward multicast traffic for the particular multicast group regardless of which of the PE routers is a DF or non-DF for the Ethernet segment.

In some examples, elected multicast forwarder module **210** may run an algorithm that divides a group network address of a multicast group stored in multicast state table **207** by a number of multi-homed PE routers in the Ethernet segment. Referring to FIG. **1**, the elected multicast forwarder module **210** may run the algorithm to divide a group network address by three, which is the number of multi-homed PE routers in Ethernet segment **14**. The result of the algorithm may indicate which of PE routers **10**A-**10**C to service a specific multicast group.

In some examples, the elected multicast forwarder module **210** may run an algorithm based on a modulo operation. For example, elected multicast forwarder module **210** may elect PE router **200** to be the elected multicast forwarder for a particular multicast group on Ethernet segment **14** when the PE router is identified as a result of the modulo operation. For example, the elected multicast forwarder module **210** may determine the remainder after a division of the multicast group network address by the number of multi-homed PE routers of Ethernet segment **14**, e.g., PE routers **10**A-**10**C, and using the remainder as an indicator whether PE router **200** should operate as the multicast forwarder for a particular group.

In some examples, elected multicast forwarder module **210** may take the join count of different groups elected by different multi-homed PE routers **10**A-**10**C by applying a hash to each of the different groups. For example, elected multicast forwarder module **210** may generate a set of hashcodes, one hash code for each multicast group. Elected multicast forwarding module **210** may sort the set of hashcodes in an ordering (e.g., ascending or descending). Elected multicast forwarder module **210** may then determine the elected multicast forwarder for a specific multicast group is, for example, the PE router associated with the hashcode that corresponds with the smallest index of the ordering.

In response to determining whether PE router **200** is to be configured as an elected multicast forwarder for a specific multicast group, elected multicast forwarder module **210** may, for example, configure PE router **200** to ignore the designated forwarder ordering and to forward multicast traffic to the specific multicast group. That is, PE router **200** may rely on the elected multicast forwarder algorithm instead of a designated forwarder algorithm when forwarding multicast traffic for a specific multicast group.

FIG. **4** is a flowchart illustrating an example operation of a provider edge router, in accordance with the techniques described in this disclosure. For illustration purposes, FIG. **4** is described with respect to PE router **200** of FIG. **3** operating as PE router **10**A of FIG. **1**. Although the examples described below are illustrated with respect to PE router **10**A, any of PE routers **10** of FIG. **1** may perform the described examples.

PE router **10**A may receive an IGMP join report including membership information to a specific multicast group for customer equipment **4** (**402**). For example, PE router **10**A may receive IGMP join report **20**A from customer equipment **4** via any of inbound links **228** that may include information that customer equipment **4** has joined a first multicast group. PE router **10**A may determine from the IGMP join report the EVI to which the IGMP join report belongs. Upon receiving the IGMP join report, PE router **10**A may instantiate an IGMP join state in its multicast state table **207** to include the first multicast group.

PE router **10**A may send a Type-7 BGP join synch route to other PE routers **10** to synchronize the join state (**404**). For example, in response to receiving the IGMP join report, PE router **10**A may install a Type-7 BGP route, e.g., a BGP join synch route, in routing information **206** and may advertise the Type-7 BGP route via any of outbound links **230** to other PE routers **10**, e.g., PE routers **10**B and **10**C, on Ethernet segment **14**. PE router **10**A may issue the BGP join synch route to all PE routers attached to Ethernet segment **14** such that each of the PE routers attached to Ethernet segment **14** may receive the BGP join synch route and to instantiate its IGMP join state in its multicast state table with the information included in the BGP join synch route. Although not shown, PE router **10**A may also receive Type-7 BGP join synch routes from other PE routers **10** such that PE router **10**A may instantiate its IGMP join state with the information included in the received BGP join synch routes.

PE router **10**A may deterministically determine whether PE router **10**A is to be configured as an elected multicast forwarder for one or more specific multicast groups (**406**). For example, PE router **10**A may include an elected multicast forwarder module **210** to run an algorithm to deterministically determine whether PE router **10**A is to be configured as an elected multicast forwarder for the one or more specific multicast groups. Other remote PE routers in the Ethernet segment may run the algorithm to determine other specific multicast groups for which the remote PE routers are to forward multicast traffic.

In response to determining that PE router **10**A is to be configured as an elected multicast forwarder for the one or more specific multicast groups, PE router **10**A may configure its forwarding state to ignore DF calculation and to forward multicast traffic for the one or more multicast groups for which PE router **10**A is the elected multicast forwarder (**408**). For example, forwarding engine **222** may be configured to ignore the designated forwarder orderings configured for Ethernet segment **14**. In this way, PE router **10**A may forward multicast traffic to the one or more specific multicast groups regardless of whether PE router **10**A is a designated forwarder or a non-designated forwarder.

PE router **10**A may receive multicast traffic via one of inbound links **226** over the EVPN core **12** (**410**). For example, in an IMET configuration, ingress PE router **10**D may flood multicast traffic to all PE routers, including PE router **10**A, over the EVPN core.

PE router **10**A may, based on the newly configured forwarding state, forward the received multicast traffic into Ethernet segment **14** for the one or more specific multicast groups (**412**). For example, in response to receiving the multicast traffic over EVPN core **12**, PE router **10**A may forward the multicast traffic into Ethernet segment **14** for the specific multicast group instead of dropping the multicast traffic as typically required for a non-designated forwarder. That is, PE router **10**A may ignore the designated forwarder calculation and proceed to forward the multicast traffic for the one or more specific multicast groups. In some examples in which PE router **10**A is a designated forwarder, PE router **10**A may forward multicast traffic only for one or more specific multicast groups for which it has been elected to be the multicast forwarder instead of forwarding traffic for all PE routers **10**.

In some examples, PE router **10**A may determine it is not to be configured as an elected multicast forwarder. In this example, PE router **10**A may continue forwarding multicast traffic based on the designated forwarder calculation (**414**). For example, if PE router **10**A is a non-designated forwarder and is not configured as an elected multicast forwarder, PE router **10**A drops the multicast traffic received over the EVPN core.

FIG. **5** is a flowchart illustrating another example operation of a provider edge router, in accordance with the techniques described in this disclosure. For illustration purposes, FIG. **5** is described with respect to PE router **200** of FIG. **3** operating as PE router **10**A of FIG. **2**. Although the examples described below are illustrated with respect to PE router **10**A, any of PE routers **10** may perform the described examples.

PE router **10**A may receive an IGMP join report including membership information to a specific multicast group for customer equipment **4** (**502**). For example, PE router **10**A may receive IGMP join report **20**A via any of inbound links **228** from customer equipment **4** that may include information that customer equipment **4** has joined a first multicast group. PE router **10**A may determine from the IGMP join report the EVI to which the IGMP join report belongs. PE router **10**A may instantiate an IGMP join state in its multicast state table **207** to include the first multicast group.

PE router **10**A may send a Type-7 BGP join synch route to other PE routers **10** to synchronize the join state (**504**). For example, in response to receiving the IGMP join report, PE router **10**A may install a Type-7 BGP route, e.g., a BGP join synch route, in routing information **206** and may advertise the Type-7 BGP route via any of outbound links **230** to other PE routers **10**, e.g., PE routers **10**B and **10**C, on Ethernet segment **14**. PE router **10**A may issue the BGP join synch route to all PE routers attached to Ethernet segment **14** such that each of the PE routers attached to Ethernet segment **14** may receive the BGP join synch route and to instantiate its IGMP join state in its multicast state table with the information included in the BGP join synch route. Although not shown, PE router **10**A may also receive Type-7 BGP join synch routes from other PE routers **10** such that PE router **10**A may instantiate its IGMP join state with the information included in the received BGP join synch routes.

PE router **10**A may deterministically determine whether PE router **10**A is to be configured as an elected multicast forwarder for one or more specific multicast groups (**506**). For example, PE router **10**A may include an elected multicast forwarder module **210** to run an algorithm to deterministically determine whether PE router **10**A is to be configured as an elected multicast forwarder for the one or more specific multicast groups. Other remote PE routers in the Ethernet segment may run the algorithm to determine other specific multicast groups for which the remote PE routers are to forward multicast traffic.

In response to determining that PE router **10**A is to be configured as an elected multicast forwarder for the one or more specific multicast groups, PE router **10**A may configure its forwarding state to ignore DF calculation and to forward multicast traffic for the one or more multicast groups for which PE router **10**A is the elected multicast forwarder (**508**). For example, forwarding engine **222** may be configured to ignore the designated forwarder ordering configured for Ethernet segment **14**. In this way, PE router **10**A may forward multicast traffic to the one or more specific multicast groups regardless of whether PE router **10**A is a designated forwarder or a non-designated forwarder.

PE router **10**A may send, e.g., a Type-6 route to request multicast traffic for the one or more specific multicast groups from ingress PE router **10**D be sent to PE router **10**A (**510**). For example, in an SMET configuration, ingress PE router **10**D may selectively forward multicast traffic for the one or more specific multicast groups to a PE router that sent the Type-6 route. As one example, PE router **10**A may send a Type-6 route requesting multicast traffic for a first multicast group.

PE router **10**A may receive multicast traffic via one of inbound links **226** based on the Type-6 route over the EVPN core **12** (**512**). For example, in an SMET configuration, ingress PE router **10**D may selectively send multicast traffic for a first multicast group to PE router **10**A because PE router **10**A sent a Type-6 route requesting to receive multicast traffic for the first multicast group.

PE router **10**A may, based on the newly configured forwarding state, forward the received multicast traffic into Ethernet segment **14** for the one or more specific multicast groups (**514**). Upon receiving the multicast traffic over EVPN core **12**, PE router **10**A may forward the multicast traffic into Ethernet segment **14** instead of dropping the multicast traffic as typically required for a non-designated forwarder. That is, PE router **10**A may ignore the designated forwarder calculation and proceed to forward the multicast traffic for the one or more specific multicast groups. In some examples where PE router **10**A is a designated forwarder, PE router **10**A may forward multicast traffic only for one or more specific multicast groups for which it has been elected to be the multicast forwarder and drop the traffic for the other multicast groups.

In some examples, PE router **10**A may determine it is not to be configured as an elected multicast forwarder. In this example, PE router **10**A may continue forwarding multicast traffic based on the designated forwarder calculation (**516**). For example, if PE router **10**A is a non-designated forwarder and is not configured as an elected multicast forwarder, PE router **10**A drops the multicast traffic received over the EVPN core.

The techniques of this disclosure may be implemented in a wide variety of devices or apparatuses, including a network device, an integrated circuit (IC) or a set of ICs (i.e., a chip set). Any components, modules or units have been described provided to emphasize functional aspects and does not necessarily require realization by different hardware units. The techniques described herein may also be implemented in hardware or any combination of hardware and software and/or firmware. Any features described as modules, units or components may be implemented together in an integrated logic device or separately as discrete but interoperable logic devices. In some cases, various features may be implemented as an integrated circuit device, such as an integrated circuit chip or chipset.

If implemented in software, the techniques may be realized at least in part by a computer-readable storage medium comprising instructions that, when executed in a processor, performs one or more of the methods described above. The computer-readable storage medium may be a physical structure, and may form part of a computer program product, which may include packaging materials. In this sense, the computer readable medium may be non-transitory. The computer-readable storage medium may comprise random access memory (RAM) such as synchronous dynamic random access memory (SDRAM), read-only memory (ROM), non-volatile random access memory (NVRAM), electrically erasable programmable read-only memory (EEPROM), FLASH memory, magnetic or optical data storage media, and the like.

The code or instructions may be executed by one or more processors, such as one or more digital signal processors (DSPs), general purpose microprocessors, an application specific integrated circuits (ASICs), field programmable logic arrays (FPGAs), or other equivalent integrated or discrete logic circuitry. Accordingly, the term "processor," as used herein may refer to any of the foregoing structure or any other structure suitable for implementation of the techniques described herein. In addition, in some aspects, the functionality described herein may be provided within dedicated software modules or hardware modules configured for encoding and decoding, or incorporated in a combined video codec. Also, the techniques could be fully implemented in one or more circuits or logic elements.

Various examples of the techniques have been described. These and other examples are within the scope of the following claims.

What is claimed is:

1. A method comprising:

receiving, by a provider edge (PE) router of a plurality of PE routers configured with an Ethernet Virtual Private Network (EVPN) instance reachable by an Ethernet segment connecting the plurality of PE devices to a customer edge (CE) router that is multi-homed to the plurality of PE routers over the Ethernet segment, an Internet Group Management Protocol (IGMP) join report for a multicast group;

sending, by the PE router and to the plurality of PE routers, one or more Border Gateway Protocol (BGP) join synch routes used to synchronize the IGMP join report for the multicast group across the Ethernet segment;

deterministically determining, by the PE router, whether the PE router is configured to be an elected multicast forwarder for at least one of a plurality of multicast groups;

in response to determining that the PE router is configured to be the elected multicast forwarder for the one of the plurality of multicast groups, configuring, by the PE router, a forwarding state of the PE router to forward multicast traffic for the one of the plurality of multicast groups into the Ethernet segment and to ignore a designated forwarder election for the Ethernet segment;

receiving, by the PE router, multicast traffic from an ingress PE router of the plurality of PE routers; and

forwarding, by the PE router, the multicast traffic into the Ethernet segment for the one of the plurality of multicast groups.

2. The method of claim **1**, wherein deterministically determining whether the PE router is configured to be the elected multicast forwarder for the one of the plurality of multicast groups comprises:

determining a result from dividing a network address of the one of the plurality of multicast groups by a number of the plurality of PE routers included in the Ethernet segment.

3. The method of claim **1**, wherein deterministically determining whether the PE router is configured to be the elected multicast forwarder for one of the plurality of multicast groups comprises:

determining a remainder result from a modulo operation dividing a network address of the one of the plurality of multicast groups by a number of the plurality of PE routers included in the Ethernet segment.

4. The method of claim **1**, wherein deterministically determining whether the PE router is configured to be the elected multicast forwarder for one of the plurality of multicast groups comprises:

determining a join count by applying a hash to each of the plurality of multicast groups.

5. The method of claim **1**, wherein receiving the multicast traffic from the ingress PE router of the plurality of PE routers comprises:

sending, by the PE router, a Selective Multicast Ethernet Tag (SMET) route for requesting multicast traffic for the one of the plurality of multicast groups from the ingress PE router; and

receiving, by the PE router and from the ingress PE router, based on the SMET route, multicast traffic for the one of the plurality of multicast groups.

6. The method of claim 1, further comprising:

in response to determining that the PE router is not configured to be the elected multicast forwarder for the one of the plurality of multicast groups, configuring, by the PE router, the forwarding state of the PE router to use the designated forwarder calculation.

7. The method of claim 1, wherein receiving the multicast traffic from the ingress PE router comprises:

receiving, by the PE router, an extended Inclusive Multicast Ethernet Tag (IMET) route that includes at least a multicast label for identifying the multicast traffic as a multicast type.

8. The method of claim 1, further comprising:

configuring, by the PE router, an extended BGP join synch route including an indication to exclude the PE router from being elected as a multicast forwarder for the plurality of multicast groups.

9. A provider edge (PE) router comprising:

a memory; and

one or more processors operably coupled to the memory, wherein the one or more processors and memory are configured to:

receive configuration data configuring the PE router with an Ethernet Virtual Private Network (EVPN) instance reachable by an Ethernet segment connecting a plurality of PE devices, including the PE router, to a customer edge (CE) router that is multi-homed to the plurality of PE routers over the Ethernet segment;

receive an Internet Group Management Protocol (IGMP) join report for a multicast group;

send, to the plurality of PE routers, one or more Border Gateway Protocol (BGP) join synch routes used to synchronize the IGMP join report for the multicast group across the Ethernet segment;

deterministically determine whether the PE router is configured to be an elected multicast forwarder for one of a plurality of multicast groups;

in response to determining that the PE router is configured to be the elected multicast forwarder for the one of the plurality of multicast groups, configure a forwarding state of the PE router to forward multicast traffic for the one of the plurality of multicast groups into the Ethernet segment and to ignore a designated forwarder election for the Ethernet segment;

receive the multicast traffic from an ingress PE router of the plurality of PE routers; and

forward the multicast traffic into the Ethernet segment for the one of the plurality of multicast groups.

10. The PE router of claim 9, wherein, to deterministically determine whether the PE router is configured to be the elected multicast forwarder for one of the plurality of multicast groups, the one or more processors and memory are further configured to:

determine a result from dividing a network address of the one of the plurality of multicast groups by a number of the plurality of PE routers included in the Ethernet segment.

11. The PE router of claim 9, wherein, to deterministically determine whether the PE router is configured to be the elected multicast forwarder for one of the plurality of multicast groups, the one or more processors and memory are further configured to:

determine a remainder result from a modulo operation dividing a network address of the one of the plurality of multicast groups by a number of the plurality of PE routers included in the Ethernet segment.

12. The PE router of claim 9, wherein, to deterministically determine whether the PE router is configured to be the elected multicast forwarder for one of the plurality of multicast groups, the one or more processors and memory are further configured to:

determine a join count by applying a hash to each of the plurality of multicast groups.

13. The PE router of claim 9, wherein, to receive the multicast traffic from the ingress PE router of the plurality of PE routers, the one or more processors and memory are further configured to:

send a Selective Multicast Ethernet Tag (SMET) route for requesting multicast traffic for the one of the plurality of multicast groups from the ingress PE router; and

receive, from the ingress PE router, based on the SMET route, multicast traffic for the one of the plurality of multicast groups.

14. The PE router of claim 9, the one or more processors and memory are further configured to:

in response to determining that the PE router is not configured to be the elected multicast forwarder for the one of the plurality of multicast groups, configure the forwarding state of the PE router to use the designated forwarder calculation.

15. The PE router of claim 9, wherein, to receive the multicast traffic from the ingress PE router of the plurality of PE routers, the one or more processors and memory are further configured to:

receive an extended Inclusive Multicast Ethernet Tag (IMET) route that includes at least a multicast label for identifying the multicast traffic as a multicast type.

16. The PE router of claim 9, the one or more processors and memory are further configured to:

configure an extended BGP join synch route including an indication to exclude the PE router from being elected as a multicast forwarder for the plurality of multicast groups.

17. A non-transitory computer-readable storage medium comprising instructions for causing one or more programmable processors to: receive configuration data configuring the PE router with an Ethernet Virtual Private Network (EVPN) instance reachable by an Ethernet segment connecting a plurality of PE devices, including the PE router, to a customer edge (CE) router that is multi-homed to the plurality of PE routers over the Ethernet segment receive an Internet Group Management Protocol (IGMP) join report for a multicast group; send, to the plurality of PE routers, one or more Border Gateway Protocol (BGP) join synch routes used to synchronize the IGMP join report for the multicast group across the Ethernet segment; deterministically determine whether the PE router is configured to be an elected multicast forwarder for one of a plurality of multicast groups; in response to determining that the PE router is configured to be the elected multicast forwarder for the one of the plurality of multicast groups, configure a forwarding state of the PE router to forward multicast traffic for the one of the plurality of multicast groups into the Ethernet segment and to ignore a designated forwarder election for the Ethernet segment; receive the multicast traffic from an ingress

PE router of the plurality of PE routers; and forward the multicast traffic into the Ethernet segment for the one of the plurality of multicast groups.

18. The non-transitory computer-readable storage medium of claim **17**, wherein, to deterministically determine whether the PE router is configured to be an elected multicast forwarder for one of the plurality of multicast groups, further comprising instructions for causing one or more programmable processors to: determine a result from dividing a network address of the one of the plurality of multicast groups by a number of the plurality of PE routers included in the Ethernet segment.

19. The non-transitory computer-readable storage medium of claim **17**, wherein, to deterministically determine whether the PE router is configured to be an elected multicast forwarder for one of the plurality of multicast groups, further comprising instructions for causing one or more programmable processors to: determine a join count by applying a hash to each of the plurality of multicast groups.

20. The non-transitory computer-readable storage medium of claim **17**, further comprising instructions for causing one or more programmable processors to: send a Selective Multicast Ethernet Tag (SMET) route for requesting multicast traffic for the one of the plurality of multicast groups from the ingress PE router; and receive, from the ingress PE router, based on the SMET route, multicast traffic for the one of the plurality of multicast groups.

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